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COSMIC GAMMA-RAYS FROM PION DECAY

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Knowledge of the production rate of $\gamma$-rays from the decay of $\pi^0$-mesons produced in interstellar cosmic-ray interactions has taken on new importance with the measurement of Kraushaar, et al.[1] indicating a value of $1.6 \times 10^{-25} S^{-1}$ per 21 cm hydrogen atom. At the same time, recent theoretical calculations have given values of $1.3 \times 10^{-25} S^{-1}$ (Ref. 2), $1.8 \times 10^{-25} S^{-1}$ (Ref. 3) and $3.2 \times 10^{-25} S^{-1}$ (Ref. 4). Basically this implies that if Ref. 2 is correct there may be some contribution to the $\gamma$-ray intensity from cool atomic hydrogen and molecular hydrogen not observed in 21 cm emission.[5] If reference 3 is correct, molecular hydrogen cannot be a significant component of the interstellar gas. If reference 4 is correct, the observation of Kraushaar et al. is thrown into question.

The three theoretical calculations referred to above involved elaborate numerical integrations to determine first the differential $\gamma$-ray spectrum and cannot be easily checked by the reader. However, if the calculation is limited to the total $\gamma$-ray intensity, a simple treatment can be given which the reader may check for himself.

Figure 1 shows the total cross section ($\sigma$) times multiplicity ($\zeta$) for neutral-pion production in a p-p interactions as a function of kinetic energy (T) as given in references (6 - 18). Fortunately, these data may be approximated by the broken power law

$$\sigma_{\pi^0}(T)\,\zeta_{\pi^0}(T) \simeq \begin{cases} 10^{-25}T^{7.64}\ \mathrm{cm}^2 & 0.4 \leqslant T \leqslant 0.7\,\mathrm{GeV} \\ 8.4 \times 10^{-27}T^{0.53}\ \mathrm{cm}^2 & T \geqslant 0.7\,\mathrm{GeV} \end{cases}$$

as the reader can verify from the figure. Taking the cosmic-ray spectrum $I(T) = 0.15T^{-2.2}\ \mathrm{cm}^{-2}\mathrm{S}^{-1}\mathrm{Sr}^{-1}\mathrm{GeV}^{-1}$ used in reference 4, the total $\gamma$-ray production rate from p-p interactions is given by

$$\begin{aligned} q_{\gamma H} &= 8\pi \int dT\ I(T)\,\sigma_{\pi^0}(T)\,\zeta_{\pi^0}(T) \\ &= 3.77 \times 10^{-25} \int_{0.4}^{0.7} T^{5.44}dT + 3.17 \times 10^{-26} \int_{0.7}^{\infty} T^{-1.67}dT \\ &= 0.66 \times 10^{-25}\mathrm{S}^{-1} \end{aligned}$$

Adding in the effect of p-$\alpha$, $\alpha$-p and $\alpha$-$\alpha$ interactions brings the total production rate per hydrogen atom up to $\sim 10^{-25}\mathrm{S}^{-1}$, a value in good agreement with early calculations.[19]

Using the upper-limit cosmic-ray spectrum given by Comstock, et al.[20], an upper limit on the $\gamma$-ray production rate is obtained of $(1.51 \pm 0.23) \times 10^{-25}\mathrm{S}^{-1}$ consistent with the upper-limit obtained by Kraushaar, et al. of $1.6 \times 10^{-25}\mathrm{S}^{-1}$ when allowance is made for hydrogen not observed in 21 cm emission measurements[5].

It should, of course, be noted that whatever the <u>shape</u> of the $\gamma$-ray production spectrum, the <u>normalization</u> has to be consistent with data on the total cross section and multiplicity.

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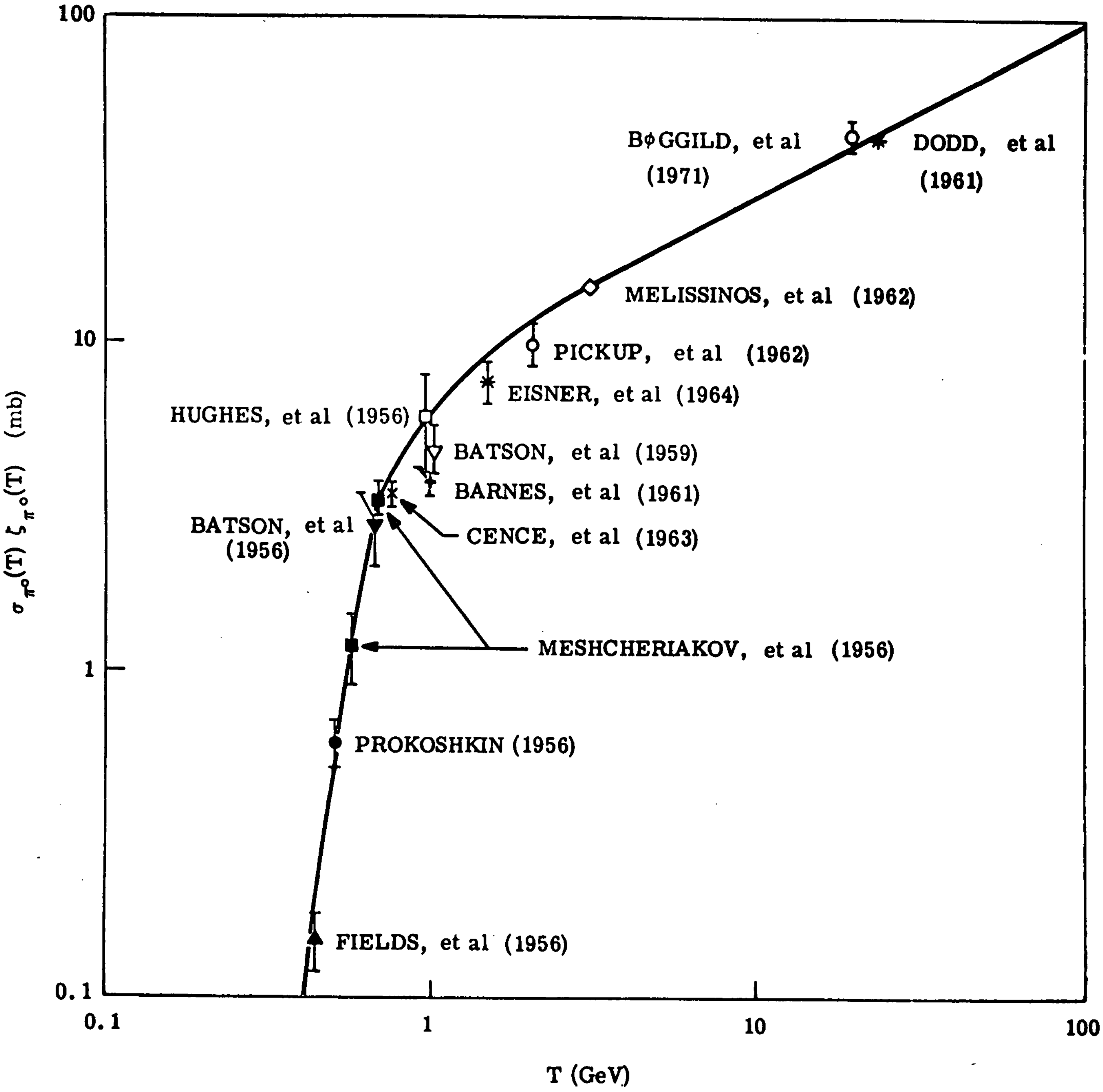

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MESHCHERIAKOV, et al (1956)
PROKOSHKIN (1956)
FIELDS, et al (1956)
100
10
1
0.1
0.1
1
10
100
$\sigma_{\pi^0}(T)\ \zeta_{\pi^0}(T)$ (mb)
T (GeV)


6

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